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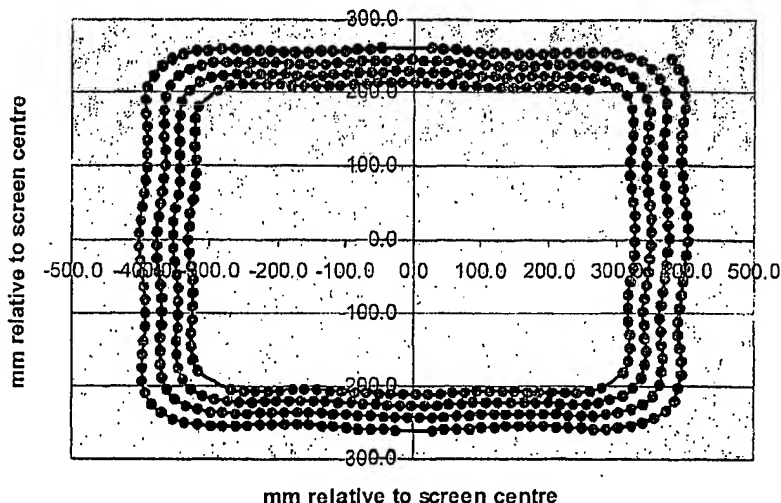
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(54) Title: **FRAME ARRAY**

**Hoolix Array**



(57) Abstract: This invention relates to acoustic "phased-array" antennas and their application to single and multi-beam directional loudspeakers and microphones, and more particularly to useful practical forms of said arrays when they have to be confined to the surrounding area of a display screen (such as in a TV or computer display). A method is shown of overcoming the major problems inherent in existing known array forms when disposed around a primarily rectangular screen. The transducers are provided in an irregular formation, such as a spiral formation or a squarised spiral formation.

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### FRAME ARRAY

The present invention relates to an apparatus for creating a sound field and a method of designing such an apparatus. More particularly, the invention provides a novel arrangement of transducers in an array type loudspeaker which alleviates the problems associated with sidelobes that can occur when sound is beamed in one or more particular directions, especially when the array contains an area devoid of transducers, such as a rectangular area used to support a display screen.

10 Phased array (and digital-delay array) loudspeakers and microphones are known in the art (see e.g. WO01/23104 and WO02/078388), and these include multi-beam arrangements useful for the production of surround sound. The arrays comprise transducers arranged in a regular pattern, such as a square grid pattern or triangular grid pattern. Non-uniformly spaced transducer arrangements are also known,

15 including logarithmic spiral arrays (see e.g. US 5,838,284). However, all of the useful arrays known have an essentially "centrally condensed" transducer layout, by which is meant that the areal density of transducers in the geometric centre of the array is comparable to or most usually greater than the areal density of transducers towards the periphery of the array. Such arrays are therefore not well-suited to be disposed

20 around the edges of a display-screen (as found in TVs and computer & electronic games displays for example). Almost all display screens are rectangular in shape, and indeed if one takes a uniform array, as disclosed in WO01/23104 for example, and simply cuts a rectangular hole in the middle for placement of the screen, in order to allow visibility of said viewing screen, poor beam shape results due to the

25 necessary absence of transducers in the central section of the array.

In the present invention, designs of physical layout of transducer arrays for Digital Delay Array Antennas (DDAA) specifically suitable for disposing about a viewing screen (of nominally rectangular form) are presented and their advantages

30 demonstrated. We do not here discuss the driver electronics and signal processing required to convert the array of transducers into a functional DDAA as these have been adequately described in previous patent applications, and no additional novelty

in that area is required for these new transducer layouts to function correctly and usefully. So it is assumed in what follows that those skilled in the art of DDAA design will understand already the signal processing implications of designing new type DDAA's with these novel transducer layouts.

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In a first aspect the invention provides apparatus for creating a sound field, said apparatus comprising: an array of sonic output transducers, which array is capable of directing at least one sound beam in a selected direction; wherein said array surrounds a central region devoid of transducers and suitable for mounting a display  
10 screen; and wherein said transducers are disposed in an irregular pattern such that any sidelobes created are at least 3 dB less powerful than the sound beam to be directed.

The irregular pattern of transducers helps to ensure that the vector separating any two  
15 transducers is different in both magnitude and angle to a vector separating any other two transducers. When a regular pattern of transducers is used there are many repeated transducer pair spacings which contribute to the creation of a few quite strong sidelobes. The irregular pattern helps to reduce the power of the sidelobes. Preferably, any sidelobes created are at least 5 dB less powerful than the sound beam  
20 to be directed and more preferably at least 10 dB less powerful than the sound beam to be directed.

Preferably, the irregular pattern is created according to a mathematical relationship. This assists in designing the apparatus and it helps when modelling the transducer  
25 positions. Preferable mathematical relationships include spirals, such as logarithmic spirals. Such spirals are preferably "squared" by including further mathematical functions that vary with theta such that there are four peaks as theta varies from 0 to 360°. For example, a function based on  $\sin^2(2\theta)$  is suitable.

30 In another aspect of the invention, there is provided apparatus for creating a sound field, said apparatus comprising: an array of sonic output transducers, which array is capable of directing at least one sound beam in a selected direction; wherein said

transducers are disposed in a rectangular spiral having horizontal and vertical perturbations in the transducer positions from an ideal rectangular spiral.

5 The use of a rectangular spiral allows the positions of the transducers to fall outside the area of a rectangular display screen. The horizontal and vertical perturbations in the transducer positions from an ideal rectangular spiral creates a certain degree of irregularity in the pattern which helps to minimise the power of sidelobes which can be created in use of the device. The use of a rectangular spiral with perturbation alleviates the creation of powerful sidelobes, even in arrays not having a central area  
10 devoid of transducers. However, the invention is clearly also of use in the case that a substantially rectangular display screen needs to be surrounded by transducers.

A third aspect of the invention also provides apparatus for creating a sound field, said apparatus comprising: an array of sonic output transducers, which array is capable of  
15 directing at least one sound beam in a selected direction; wherein said array surrounds a central region devoid of transducers and suitable for mounting a display screen; and wherein said transducers are disposed in a spiral around said central region.

20 The use of a spiral transducer position, rather than a regular grid transducer position, alleviates somewhat the problems with powerful sidelobes being inadvertently or accidentally created. Even better performance can be obtained by ensuring that the inter-transducer spacing, measured along the line of the spiral itself, is irregular.

25 The invention provides in a fourth aspect a method of designing a sonic transducer array, said method comprising: determining a display screen area; defining a spiral curve around said display screen area upon which transducers may be placed such that said transducers do not mechanically interfere with each other or a display screen when the same is placed in said display screen area; determining the positions  
30 of each transducer along said spiral curve.

The use of a spiral curve in designing the transducer array allows the transducers to, on the one hand, be located in a fairly dense grouping around the periphery of the display screen (thereby ensuring that the overall apparatus size is not too large), and, on the other hand, helps to avoid a regular grid pattern being provided which can  
5 cause the creation of deleterious sidelobes.

It assists in designing the array if the curve is defined using a mathematical relationship.

10 As well as a method of designing the array, the invention also includes a method of creating a sound field in which at least one sound beam is directed using an array of sonic output transducers, the output transducers being positioned such that any sidelobes created are at least 3 dB less powerful than the sound beam to be directed. Preferably the apparatus comprises a central region devoid of transducers. The  
15 irregular pattern is preferably a spiral and more preferably a squarised spiral.

Before describing the invention in detail with reference to preferred embodiments, several definitions of terms are given to aid in understanding the invention.

20 Definitions

The "Hoolix": The term "Hoolix" is coined to refer to a family of curves that have some of the properties of squares (or more generally rectangles) and some of the properties of spirals. A square or rectangular "curve" is a closed loop that has four  
25 straight-line segment sides in two parallel pairs (with each segment of a parallel pair having equal length, and the segments in each pair being orthogonal to the segments in the other pair, and for the square as opposed to rectangle case, the lengths of segments in each pair are also identical to each other). Also included within the definition of Hoolix such parallel pairs of line segments where the orthogonality  
30 constraint is dropped (in which case the forms of the loops are what are colloquially called "diamonds" and technically parallelograms).

A spiral curve is (except in the limiting case) here defined as a non-closed-loop curve which, with the increase of some parameter  $t$ , takes successively increasing or decreasing values of polar angular coordinate  $\theta$  about some origin  $O$  and which takes successively increasing or decreasing values of radial coordinate  $r$  from that same origin  $O$ . The particular nature of the functional relationship between  $r$ ,  $\theta$  and  $t$  determines the exact form of said spiral. In Simple Spirals, the increase or decrease of  $r$  and  $\theta$  with  $t$  are both monotonic. Complex Spirals are defined as otherwise similarly defined curves, wherein the increase or decrease of  $r$  and  $\theta$  with  $t$  are non-monotonic, but nonetheless where for each increase of  $\theta$  by  $2\pi$  radians, the related increase or decrease of  $\theta$  integrated over that  $2\pi$  range of  $\theta$  is monotonic. Thus, Complex Spirals generally grow or shrink in radius with gross changes in  $\theta$  but may also have "wiggles". Common forms of Simple Spirals are the linear spiral,  $Slin(t)$ :

$$\begin{aligned} \theta(t) &= k_1 * t; & [\text{polar angle of } Slin(t) \text{ as a function of } t] \\ r(t) &= k_2 * t; & [\text{polar radius of } Slin(t) \text{ as a function of } t] \\ &[\text{here "*" represents multiplication}] \end{aligned}$$

where  $k_1$  and  $k_2$  are constants;

and the logarithmic spiral,  $Slog(t)$ :

$$\begin{aligned} \theta(t) &= k_1 * t; \\ r(t) &= k_2 * \exp(k_3 * t); \end{aligned}$$

where the radius is no longer a simple linear function of  $t$  and thus of  $\theta$ , but is nonetheless monotonic as defined above.

However, any curve which meets the above definition of Simple or Complex Spiral is included within the following definition of a Hoolix.

Combining these two sets of properties (squares and spirals) a general Hoolix is defined as any curve that meets the definition of Simple or Complex Spiral as given above, and which simultaneously has the property that certain contiguous sections of the curve opposite to each other with respect to the origin of the curve  $O$ , are approximately straight and approximately parallel, insofar as curves (rather than

straight lines) may be said to be "parallel" at all. For clarity, below a definition of "approximately straight" and of "approximately parallel" is given. A more specialised form of Hoolix, the Parallelogram Hoolix, has just two pairs of such opposite approximately-parallel sections per (approximately)  $2\pi$  radian increase in theta. An even more specialised form of Hoolix, the Rectangular Hoolix, is a form of Parallelogram Hoolix where adjacent (connected) approximately straight sections of the curve are approximately at right angles to each other. Finally a more specialised form of Rectangular Hoolix, the Square Hoolix has such adjacent approximately straight sections of the curve, also of approximately the same length as each other, giving the curve a squarish spiral shape.

"Approximately Straight": A section of a continuous curve  $C(t)$ ,  $C_x = F_x(t)$ ,  $C_y = F_y(t)$ , from point  $A = C(t_1)$  at  $t = t_1$  to point  $B = C(t_2)$  at  $t = t_2 = t_1 + 2dt$ , is "Approximately Straight" if it meets the following criterion:

The curve between A & B may be entirely contained within a rectangular boundary passing through A and B, where the aspect ratio of said rectangle is more than 3:1, or preferably more than 5:1, or more preferably still, more than 10:1. In general there will be just one smallest possible bounding rectangle completely enclosing the curve between A & B [smallest in area] and the angular position of the longer side of said smallest bounding rectangle is then said to be the "slope-direction" of the curve segment between A & B.

"Approximately Parallel": Two sections  $C_1(t)$  and  $C_2(t)$  of continuous curves are said to be "Approximately Parallel" if their slope-directions are within 30deg of each other, or preferably within 15deg of each other or more preferably within 5deg of each other.

"Approximately at Right Angles": Two sections  $C_1(t)$  and  $C_2(t)$  of continuous curves are said to be "Approximately at Right Angles" if their slope-directions are within 90deg plus or minus 30deg from each other, or preferably are within 90deg plus or minus 15deg each other or more preferably are within 90deg plus or minus

5deg each other.

The invention will now be further described by way of non-limitative example only, with reference to the accompanying drawings, in which:-

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Fig. 1 shows an array of transducers that might be obtained if a standard regular pattern of prior art transducers is modified so as to provide a central area devoid of transducers for the mounting of the display screen;

Fig. 2 shows an array of transducers laid out along a Hoolix curve according to one aspect of the present invention;

Fig. 3 shows some functions that can be used to create a Hoolix curve;

Fig. 4 shows a plan view of the beam shape obtained when the array of Fig. 2 is used, at 10 kHz;

Fig. 5 shows a  $2\pi$  radian beam plot for the same Hoolix array and frequency as Fig. 4;

Fig. 6 is similar to Fig. 4 but is for a uniform rectangular array with a hole in the middle, similar to that shown in Fig. 1; and

Fig. 7 is similar to Fig. 5, but shows a  $2\pi$  radian beam plot for a uniform rectangular array having a hole in the centre.

20

Consider a modern liquid crystal display (LCD) monitor or TV, typically of about 61 cm (24 inches) diagonal size, and a few centimetres thick. With the physical structure required around the screen for mounting and protection, such an LCD monitor (hereinafter simply LCD) is perhaps 61 cm (24 inches) wide by 36 cm (14 inches) high. If it was desired to place this LCD in the middle of a conventional regularly spaced DDAA (which could be used as the surround sound audio system associated with the LCD video screen) then there would necessarily be a hole in the DDAA (where the LCD was) at least 61 cm x 36 cm. 61 cm is the wavelength of sound of frequency ~550Hz and 36 cm the wavelength of sound of frequency ~940Hz.

Because of the hole in the DDAA the sections of antenna either side of the screen (formed by the adjacent array of transducers there) would form an interferometer at frequencies above ~ 550Hz, and thus, were the DDAA to be used as a transmission



antenna, then full power aliases in the horizontal plane would be expected at many frequencies higher than ~550Hz within the audible band, which would greatly detract from the functionality of the DDAA for surround sound purposes. Similar alias beam problems in the vertical plane would be produced by the hole, above a frequency of ~940Hz. The apparatus proposed in Fig. 1 suffers from such a problem. This apparatus is rectangular and has a central rectangular screen measuring 61 cm x 36 cm. There are 480 transducers in all, each transducer having a diameter of 13 mm with a centre to centre spacing of about 18 mm. The transducers are disposed in a regular square grid pattern.

10

The present invention proposes to reduce these problems by positioning the transducers forming the DDAA around the LCD screen, not in a regular grid pattern, but instead, laying them down in an irregular pattern. For example in a spiral pattern or at successive positions along a carefully designed Rectangular Hoolix curve (defined above). Said Hoolix curve is designed to have a starting point  $> \sim$  one transducer radius from a point on the outer edge of the LCD screen (and more usefully perhaps near a corner of said screen) and then proceeds in a clockwise or anticlockwise fashion around said screen such that its first Hoolix turn (by analogy with a first spiral turn) (i.e. its geometric trajectory with, say, increasing parameter  $t$ ) closely follows the border of the screen, but at all or nearly all points remains greater than one transducer radius from the screen edge. Thus transducers may be positioned along said Hoolix trajectory without mechanically interfering with the LCD screen structure. By the time the Hoolix curve has completed one revolution of the screen, it is designed to now be  $> \sim 1$  transducer diameter greater in radial distance from the screen centre than at its starting point, so that successive transducers laid out along its trajectory now do not interfere with those laid out along the first turn.

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The two predominantly straight and parallel pairs of "sides" of the Hoolix are designed to be approximately parallel to the two sets of parallel edges of the LCD screen. More and more Hoolix turns may then be "wrapped" around the screen, with gradually increasing polar radii, transducers being laid along the curve as before, such that none of the transducers mechanically interfere with any others, or with the

30

LCD screen structure. Typically two to four Hoolix turns of transducers will suffice to produce a useful DDAA. As to how to lay out the transducers along the Hoolix trajectory: a simple and useful strategy is to place a first transducer at the Hoolix starting point as described above, and thereafter to place successive transducers an

5 approximately fixed distance from the previous one, as measured along the Hoolix curve/trajectory. The value of this ~fixed distance is a free parameter but again, typically, a useful value is one to two transducer diameters, although greater spacings also work usefully. Smaller spacings would necessarily produce mechanical interference between adjacent transducers. However, non-fixed or irregular

10 transducer-transducer spacings are also useful, particularly spacings that increase slowly with successive distance along the Hoolix trajectory from the inner starting point, so that the outer "ring" of transducers has greater inter-transducer spacing than the inner ring of transducers. As the Hoolix turns can also have successively greater turn-to-turn spacing (if for example the Hoolix is not of the simple linear Hoolix

15 form) then the two successively increasing transducer spacing parameters (i.e. along the curve and between turns of the curve) allow for the use of larger transducers towards the outside of the Hoolix DDAA which are generally better for the reproduction of lower frequencies.

20 The transducers themselves are preferably chosen so that they have the desired audio bandwidth, and, are preferably of a diameter such that they are reasonably non-directional over the frequencies of interest for controlling by the DDAA. These requirements usually imply that the transducer diameters are smaller than an acoustic wavelength (in air or the DDAA working fluid) at, at least, half the maximum

25 operating frequency of the transducers in the DDAA (NB not all said transducers necessarily operate over the whole DDAA bandwidth, and there are specific advantages to be had by giving greater emphasis to lower frequencies towards the outside transducers of the Hoolix and greater emphasis to the higher frequencies towards the inner transducers of the Hoolix). So, e.g. for a hi-fi surround system for

30 use with a TV or computer monitor, the maximum frequency of interest would probably lie in the region from 16KHz to 20KHz, implying an acoustic wavelength of half these frequencies, i.e. 43mm to 17mm, and thus transducer diameters, (at least

those transducers in the high-frequency region of the DDAA array which are preferably positioned closest to the LCD screen edge), within this range or smaller.

A particular form of DDAA designed along these lines is shown in Fig. 2. It has 480  
5 transducers of diameter 13mm distributed along such a Hoolix curve at centre to  
centre spacing distance of ~18mm. The positions of the points plotted correspond to  
the (x, y) coordinates given Table 1 below. The transducers are driven in adjacent  
pairs (adjacent along the Hoolix curve trajectory) for a total of 240 driver amplifiers  
(to reduce cost and complexity). The actual transducer centre coordinates used for  
10 this specific DDAA are shown in Table 1 annexed to the end of the description,  
where each triplet of columns represents; i) a transducer reference number, 1 to 480;  
ii) a transducer x-coordinate in mm (chosen to be a horizontal position, i.e. the  
direction parallel to the long edge of the LCD screen used); and iii) a transducer y-  
coordinate in mm. Thus the first three columns show the positions of the first 60  
15 transducers, the next three columns the positions of the next 60 transducers, and so  
on for a total of 480 transducers. Inspection of the coordinates will show that there  
are some gaps in a continuous evenly spaced set of transducer positions along the  
chosen Hoolix curve. These gaps are where transducers have been omitted from the  
DDAA because the position of such transducers would have caused them to  
20 mechanically interfere either with the LCD screen on the inside of the DDAA, or the  
outside casing of the DDAA, designed to be rectangular and approximately parallel  
to the LCD screen, and as compact as possible. Such omitted transducers, if small in  
number, from the otherwise continuous array cause only small imperfections in the  
DDAA beam shape and are not a problem, and this flexibility in choice of actual  
25 transducer locations is very helpful when designing real arrays with specific  
functional or product requirements.

Plotting of the presented coordinates, as has been done in Fig. 2, will show that there  
is a large blank area within the layout of transducers, quite large enough to house a  
30 commercially available 61 cm (24 inch) LCD computer monitor screen. The  
performance of this DDAA array exemplified by the coordinate table below, has  
been computer modelled and verified experimentally and found to behave

extraordinarily well as a single-box surround sound DDAA system. A woofer, positioned in a long thin box beneath the screen and DDAA, was used to reproduce frequencies below ~300Hz because of the low-frequency limitations of the 13mm transducers used in the array - however, the latter perform extremely well up to the highest audible frequencies and are exceptionally omnidirectional (in a half space) because of their small diameter.

The analytical form of the particular Hoolix curve used for the DDAA just described is:

$$\begin{aligned} x &:= \text{radx} * \exp(b * (\text{theta} + \text{th0})) * (1 + \text{sqrn} * \exp(-\text{gg} * (1 - \sqrt{\sin(2 * \text{theta})}))) * \\ &\cos(\text{theta} + \text{th0}); \\ y &:= \text{rady} * \exp(b * (\text{theta} + \text{th0})) * (1 + \text{sqrn} * \exp(-\text{gg} * (1 - \sqrt{\sin(2 * \text{theta})}))) * \\ &\sin(\text{theta} + \text{th0}); \end{aligned}$$

where:

(x, y) are the coordinates of a point along the Hoolix trajectory;

theta is the polar angle of the curve; this is the parameter that successively increases or decreases as one follows the trajectory of the curve;

radx and rady are characteristic dimensions of the curve in the directions of the X-axis and Y-axis respectively, so that the curve may have any desired aspect ratio, and thus be matched to, for example, a 16:9 display screen;

b and th0 are a pair of parameters analogous to those found in the simple logarithmic spiral curve and are related to the scale of the curve and its starting angle;

sqrn is a parameter,  $0 < \text{sqrn} \leq 1.0$ , which determines the "squareness" of the Hoolix curve, with  $\text{sqrn} = 0$  leaving the curve a pure spiral with no squareness, and  $\text{sqrn} = 1.0$  producing a Hoolix with high squareness;

gg is another scaling parameter relating to the amount of squareness produced;

sqrt() is the square root function;

The remarkable thing about the DDAA just described, and about all such properly designed DDAA's using irregular patterns such as spiral curve or Hoolix curve

geometry, is that despite the transducer array having a large "hole" in it, wherein sits the display screen, the alias beam-performance and sidelobe-performance are good, and exceptionally good in the case of the Hoolix curve, and certainly more than adequate for most multi-beam sound systems.

5

The principal feature of the above described irregular transducer layouts for DDAA's, is that the resulting set of transducer positions does not result in many or any identical transducer-pair spacings and angular orientations. By this is meant that if one takes each transducer in turn, and pairs it with each and every other transducer in the array, the set of all spacing and relative angular directions of such pairs will form a smooth distribution with few if any peaks. Compare this with the situation if the transducers were laid out in a regular rectangular or triangular array with a hole in it (e.g. a hole large enough to place a plasma or LCD screen of say 24 inches or more). Because of the regular transducer position grid in these cases the distribution of all pairings would have many distinct and strong peaks in it. The effect of the smooth distribution in the irregular (e.g. Hoolix) case is to produce only (many) weak sidelobes; and in the case of the peaky distribution of the regular array, to produce a few very strong sidelobes. So use of the Hoolix layout produces a sharp main beam surrounded by a broad but low floor of weak sidelobes, with no strong sidelobes present, which is unattainable with a regular array surrounding a hole.

20

A regular rectangular spiral arrangement where the transducers are all equispaced along a set of orthogonal straight lines surrounding the hole in the array offers some improvement over a regular array but can still produce sidelobes which lower the usability of the arrangement as a DDAA array for some applications. An improvement over the regular rectangular spiral can be achieved by using non-constant transducer spacing (along the square-spiral) and by using non-constant square-turn spacing – these measures flatten out somewhat the distribution of transducer pair spacings. However, the fact that many transducers still share the same horizontal and/or vertical coordinates (because of the rectangular layout) means that the sidelobes produced by each pair tend to stack up along particular directions. This effect is further reduced by applying horizontal and/or vertical perturbations to the

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“ideal” positions in the square spiral. By doing this, an arrangement similar to the Hoolix curve in Fig. 2 is achieved.

Fig. 3 shows the mathematical development of a particular Hoolix curve. The basis form is the Circle. Various “Squarising” functions are also shown, including;  
 5  $Sq1 = \text{SQRT}(\text{radx} \cdot \text{rady}) \cdot \text{SIN}(2 \cdot \text{theta})^2$ , and  $Sq2 = (\text{SQRT}(\text{radx} \cdot \text{rady}) \cdot \text{SIN}(2 \cdot \text{theta})^2)^2$ , and  $Sq3 = \text{EXP}(-\text{gg} \cdot (1 - (\text{SIN}(2 \cdot \text{theta})^2)))$  [this function labelled “Gauss” in Fig. 2], where “^” means raised to the power, “\*” denotes multiplication, “SQRT” denotes square root, and “theta” is the polar angle of  
 10 the function. “gg” is a free parameter which determines the degree of Squarising. A fourth Squarising function Sq4 is also shown. Labelled “sqf” in Fig. 3, and this is a linear combination of Sq1, Sq2 and Sq3 of the form  $\text{sqf} = \text{aa} \cdot \text{Sq1} + \text{ab} \cdot \text{Sq2} + \text{ac} \cdot \text{Sq3}$ , where aa, ab, and ac are free parameters, usefully in the range 0 to 1.0. The Circle is “Squarised” by multiplying its normally fixed radius r by one of the Squarising  
 15 functions, with  $\text{radx} = \text{rady} = r$ . An Ellipse can similarly be squarised, by multiplying its radius (already a function of theta) by a Squarising function. Finally, Fig. 3 shows a Hoolix curve, in this case produced from a basis curve which is a logarithmic spiral, but again where its radius, already a function of theta, is multiplied by a Squarising function, in the case illustrated, Sq3 (Gauss) being used.

20

Fig. 4 shows a plan view of the beam shape of a Hoolix array, at 10KHz, where the array is at bottom centre of the figure. The Figure represents an 8m square area in front of the array. In this plot the beam is focussed at a point 3m away directly in front of the array (above in the picture), so focussed nearly at the centre of the array.  
 25 The amplitude scale is shown on band at the RHS of the plot, the colour/shading at the top of the band representing 0dB, that at the bottom -50dB. A strong well focussed beam is evident with sidelobes lower than 15dB to 20dB down.

Fig. 5 shows a 2pi radian beam plot (akin to a Mercator Map projection), for the  
 30 same Hoolix array and frequency as Fig. 4. The beam is again focussed at 3m from the array. The horizontal centre line of the plot represents longitudinal angles from -90 to +90 degrees, at zero latitude. The vertical centre line represents latitudinal

angles from +90deg through 0deg at plot centre to -90deg, at zero longitude. The N and S poles are spread right along the top and bottom of the plot respectively. The amplitude scale is again shown by the band at the RHS with 0dB at the top and -20dB at the bottom. Where the plot is white the amplitude is more than -20dB down.

5 There is clearly a well focussed central beam with marginal sidelobes, even at 10KHz.

Fig. 6 is directly comparable with Fig. 4 but is for a uniform rectangular array with a hole in the middle, similar to that shown in Fig. 1. While a strongly focussed beam is

10 visible, there are clearly very many strong sidelobes (principally due to the hole in the middle of the array) making this simple approach useless for most applications.

Fig. 7 is directly comparable with Fig. 5 but is again for the uniform rectangular array. What now becomes apparent is that the strong sidelobe pattern for this simple

15 array extends in both vertical and horizontal directions.

Table 1: Transducer positions as shown in Figure 2



CLAIMS

1. Apparatus for creating a sound field, said apparatus comprising:  
an array of sonic output transducers, which array is capable of directing at  
5 least one sound beam in a selected direction;  
wherein said array surrounds a central region devoid of transducers and  
suitable for mounting a display screen; and  
wherein said transducers are disposed in an irregular pattern such that any  
sidelobes created are at least 3 dB less powerful than the sound beam to be directed.  
10
2. Apparatus according to claim 1, wherein said irregular pattern is  
created according to a mathematical relationship.
3. Apparatus according to claim 2, wherein said mathematical  
15 relationship is a logarithmic spiral that has been squarised by sine or cosine  
functions.
4. Apparatus for creating a sound field, said apparatus comprising:  
an array of sonic output transducers, which array is capable of directing at  
20 least one sound beam in a selected direction;  
wherein said transducers are disposed in a rectangular spiral having  
horizontal and vertical perturbations in the transducer positions from an ideal  
rectangular spiral.
- 25 5. Apparatus according to claim 4, wherein said array surrounds a  
central region devoid of transducers and suitable for mounting a display screen.
6. Apparatus for creating a sound field, said apparatus comprising:  
an array of sonic output transducers, which array is capable of directing at  
30 least one sound beam in a selected direction;  
wherein said array surrounds a central region devoid of transducers and  
suitable for mounting a display screen; and

wherein said transducers are disposed in a spiral around said central region.

7. Apparatus according to any one of claims 3 to 6, wherein transducers are laid out along said spiral path with an irregular inter-transducer spacing along the  
5 line of said spiral.

8. Apparatus according to any one of the preceding claims, wherein it is arranged such that said at least one sound beam is created using substantially all the transducers in the array.  
10

9. Apparatus according to any one of the preceding claims, wherein said central region devoid of transducers is substantially rectangular.

10. An audio-visual device including a display screen and an apparatus  
15 for creating a sound field according to any one of the preceding claims.

11. An audio-visual device according to claim 10, wherein said audio-visual device is a television.

20 12. An audio-visual device according to claim 10, wherein said audio-visual device is a computer monitor.

13. A method of designing a sonic transducer array, said method comprising:  
25 determining a display screen area;  
defining a spiral curve around said display screen area upon which transducers may be placed such that said transducers do not mechanically interfere with each other or a display screen when the same is placed in said display screen area;  
30 determining the positions of each transducer along said spiral curve.

14. A method according to claim 10, wherein said curve is defined using a mathematical relationship.

15. A method according to claim 11, wherein said curve is a squarised  
5 spiral.

16. A method according to any one of claims 10 to 12, wherein said curve and said positions along the curve are determined such that any sidelobes created are at least 3 dB less powerful than the sound beam to be directed.

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FIG. 1.

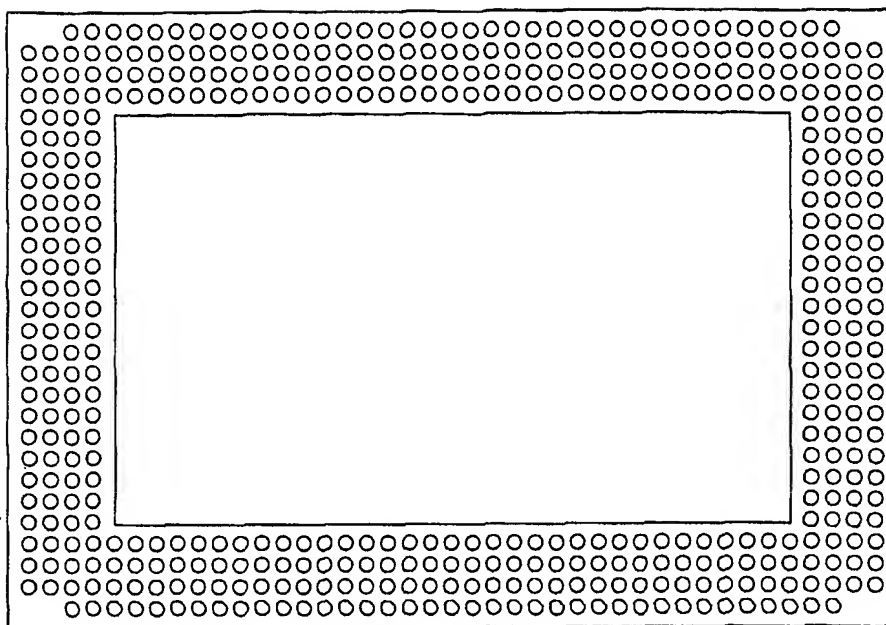
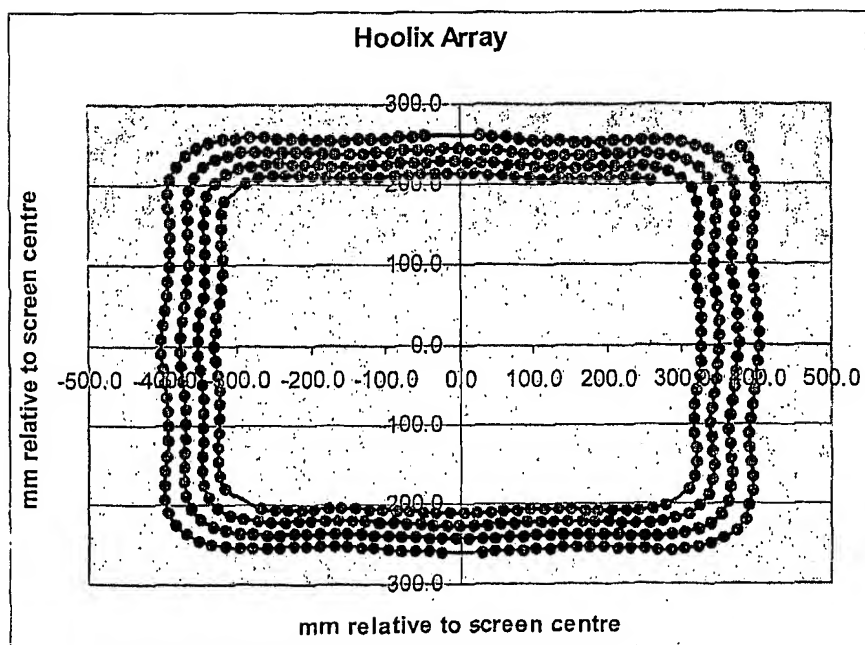
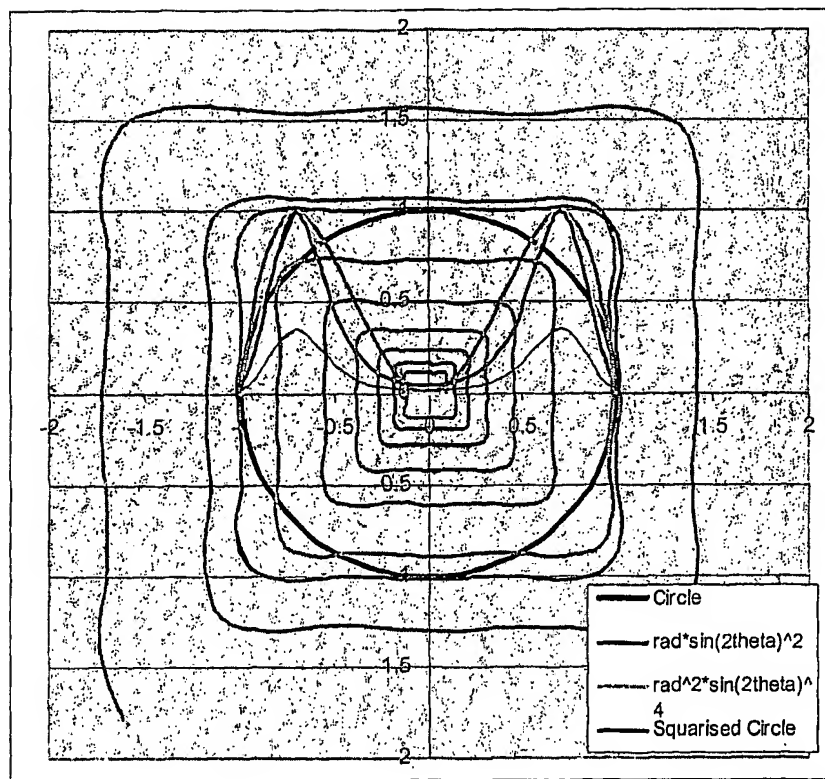


FIG. 2.



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FIG. 3.



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FIG. 4.

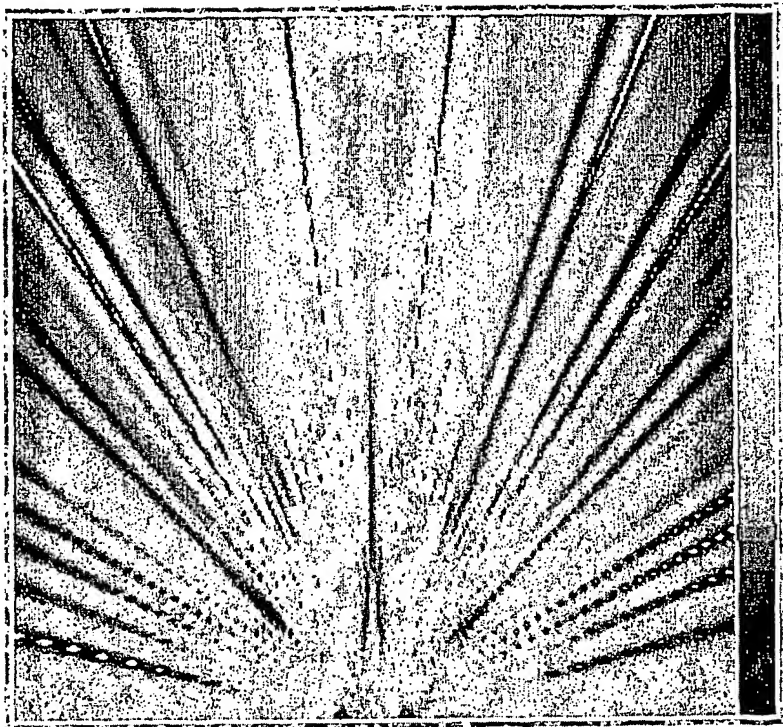


FIG. 5.

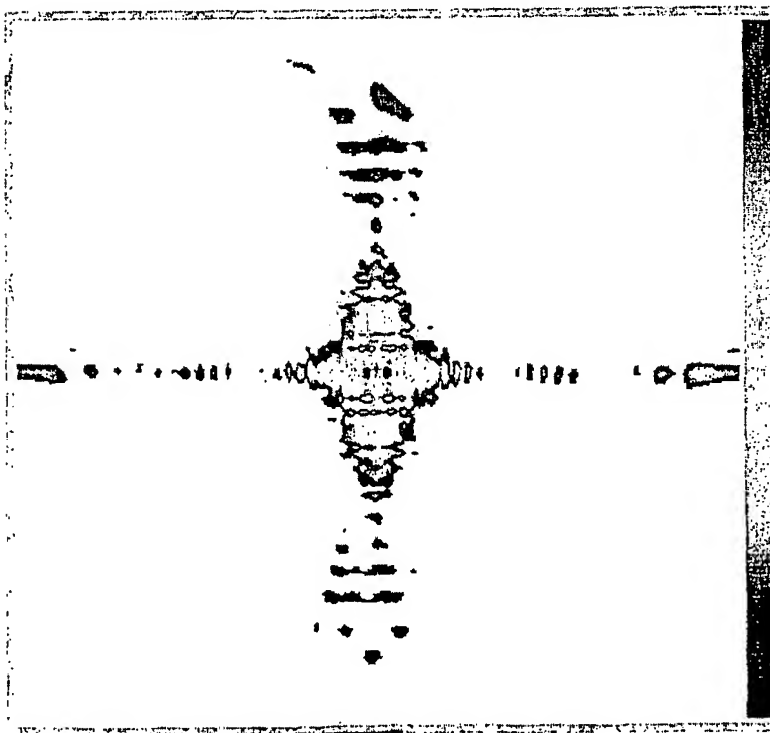


FIG. 6.

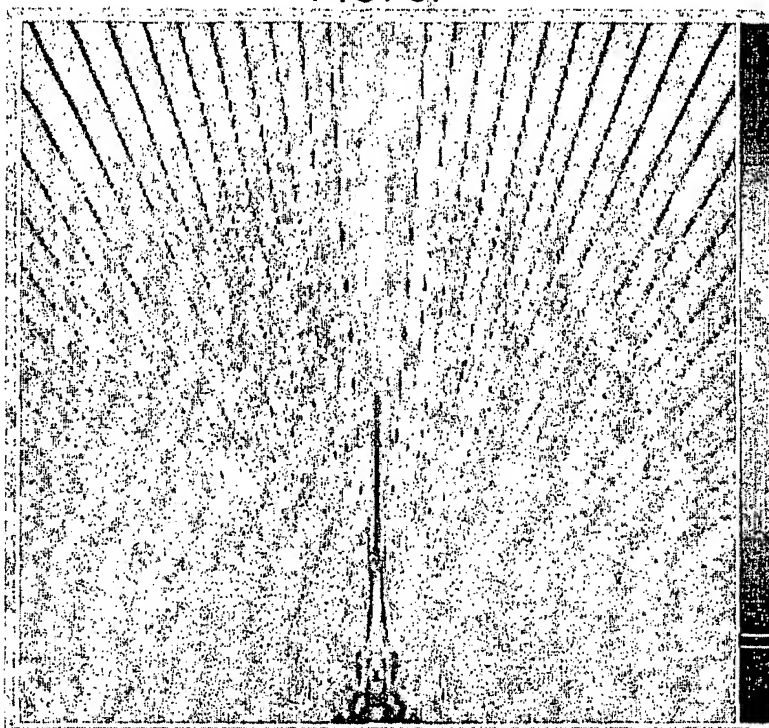
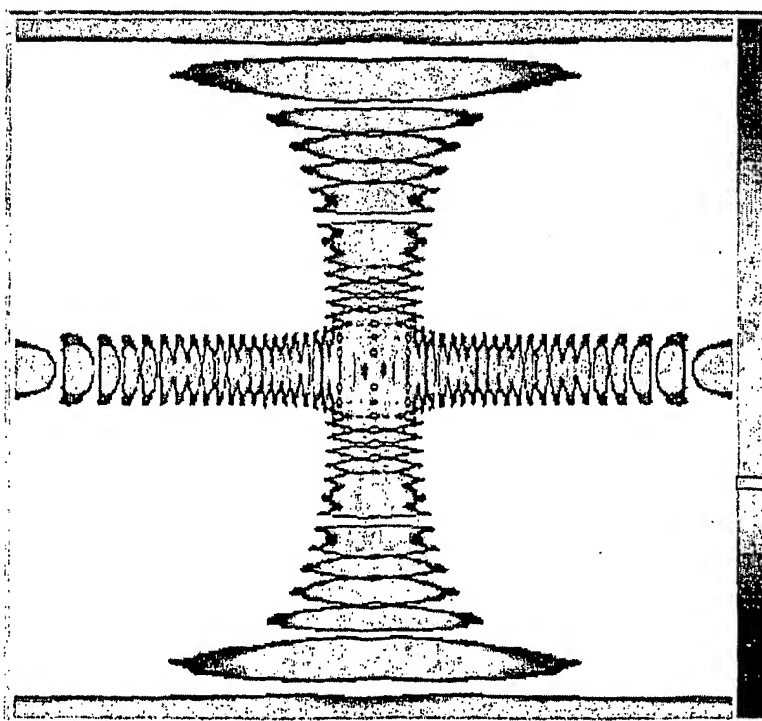


FIG. 7.



# INTERNATIONAL SEARCH REPORT

International Application No  
PCT/GB2005/003528

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 7 H04R1/40 H04R3/12

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H04R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC, COMPENDEX

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	EP 0 323 110 A (MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD) 5 July 1989 (1989-07-05)  column 3, line 3 - line 45 figure 4	1,2,8-12  3-7, 13-16
Y A	WO 2004/075601 A (1...LIMITED; HOOLEY, ANTHONY; LENEL, URSULA, RUTH; GOUDIE, ANGUS, GAVI) 2 September 2004 (2004-09-02)  page 8, line 1 - page 10, line 4 page 17, line 17 - page 28, line 6 page 33, line 7 - page 36, line 8	1,2,8-12  3-7, 13-16

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

10 November 2005

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17/11/2005

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# INTERNATIONAL SEARCH REPORT

International Application No  
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 807 990 A (THE BOEING COMPANY) 19 November 1997 (1997-11-19) the whole document -----	1-16

# INTERNATIONAL SEARCH REPORT

International Application No  
PCT/GB2005/003528

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
EP 0323110	A	05-07-1989	CA 1325540 C DE 3884591 D1 DE 3884591 T2 KR 9107182 B1 US 4998283 A	28-12-1993 04-11-1993 27-01-1994 19-09-1991 05-03-1991
WO 2004075601	A	02-09-2004	NONE	
EP 0807990	A	19-11-1997	CA 2204298 A1 CN 1169540 A DE 69705357 D1 DE 69705357 T2 JP 10093335 A US 6205224 B1	17-11-1997 07-01-1998 02-08-2001 11-10-2001 10-04-1998 20-03-2001